SWITCH MODULATION TECHNIQUES

REPORT NO. 3

CONTRACT No. DA 36-039-SC-87353

DEPARTMENT OF THE ARMY TASK NO. 3A99-09-002-05

Third Quarterly Progress Report

1 FEBRUARY 1962 to 30 APRIL 1962

PREPARED FOR

U.S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY

FORT MONMOUTH, NEW JERSEY

GENERAL ELECTRIC

DEFENSE ELECTRONICS DIVISION • ADVANCED ELECTRONICS CENTER

CORNELL UNIVERSITY INDUSTRY RESEARCH PARK • ITHACA • NEW YORK

SWITCH MODULATION TECHNIQUES

REPORT NO. 3

CONTRACT No. DA 36-039-SC-87353

Signal Corps Technical Requirement SCL-7575
Dated 23 September 1960

DEPARTMENT OF THE ARMY TASK No. 3A99-09-002-05

Third Quarterly Progress Report

1 FEBRUARY 1962 to 30 APRIL 1962

FEATURES OF THE FREQUENCY-MODULATED SELF-STABILIZING POWER MODULATOR

Prepared by Francisc C. Schwarz

TABLE OF CONTENTS

I. PURPOSE

Work on this contract is directed toward an investigation of potential improvements in the area of power supplies in the light of advancements of circuit concepts and technology of components.

Improvements are sought with respect to higher reliability and efficiency, associated with reductions of physical size and weight. Another intended improvement is seen in a relatively wide range of adaptability of these power supplies to supply line voltages and frequencies. The exclusive use of silicone semiconductor devices as nonlinear resistive two-terminal and three-terminal circuit components and the application of advanced concepts in the design of iron core devices contribute to the establishment of all solid-state circuits for the purpose under consideration.

Theoretical and experimental studies (Item 1) will be reinforced by construction of two different experimental models, to conform to the specifications as listed in the following:

Item 2:

Power Converter: ac to dc

Input: single phase 115/230 volts ac rms ±10 percent, 50/60/400 cps ± 5 percent

Output: 26 volts dc, 0 to 10 amp dc

Regulation: ±1 percent under any combination of line voltage variation and no load to full load current variations

Ripple: 0.5 percent peak to peak

Ambient Temperature: -55 to +65 C

Load: resistive load

Item 3:

Power Converter: ac to dc, as specified for Item 2, except:

Output: 22 to 30 volts dc, 0 to 20 amp dc, continuously adjustable

During the first quarter, work was initiated by a preliminary study phase of this program, and was carried out at the Advanced Electronics Center in Ithaca, New York, and the Electronics Laboratory, Syracuse, New York, both within the Defense Electronics Division of the General Electric Company. Two different concepts were studied during this period and discussed between representatives of USAERDL, Fort Monmouth, and the General Electric Company during a conference in Ithaca on 27 October 1961. All parties agreed that work should be continued in Ithaca and directed toward a construction of a breadboard model conforming to the specifications of Item 2, and applicable to modifications to conform to the specification of Item 3.

Work carried out in the second period was devoted to further theoretical and experimental study of the frequency-modulated self-stabilizing (FM-SS) modulator and its integration into the power supply under development. Solutions for technical problems were sought with respect to loading conditions, including no-load and short-circuited terminals. Further efforts were directed toward the understanding and solution of an unsatisfactory open loop regulation. Information was sought for the design of wire-wound power components and required characteristics of semiconductor components.

The purpose of the work during the third quarter was the establishment of a breadboard incorporating all functions of the system and the establishment of electronic schematics and mechanical design for the experimental units, as well as their physical construction.

II. ABSTRACT

The saturable reactors were replaced by an electronic integrator, simulating operation of the saturable reactors with an improvement in accuracy of roughly two orders of magnitude. The entire control system was redesigned and reduced to practice following the discovery of insufficient accuracy in functional aspects, which were not apparent with operation of saturable reactors. A breadboard of the 260-watt unit except feedback and reference sources was established and brought to operation. An automatic adjustment of the system to the two line voltages in question, 115 and 230 v ac respectively, was devised. Electrical and mechanical design of units (Items 2 and 3 of the contract) was completed and schematics established. Physical construction of experimental units is well advanced (see Figures 1 and 2).

Preliminary test data of the 260-watt experimental model indicate that all of the goals of this contract should be attainable. An active filtering effect of the FM-SS power modulator in excess of three was achieved, as expected, and secures the weight and size reduction of the bulky dc filters by a comparable factor. Weight and size reduction of the power transformer by application of inversion techniques exceeds expectations, and reduces this to a secondary problem. Positively fail-safe SCR operation as inherent in a series inverter with logic firing control was experimentally ascertained under very severe aperiodically recurrent and varying transient conditions. Output voltage regulation and ripple are within specifications. An automatically recycling overload protection provision secures re-establishment of the output voltage, when overload, including short-circuited output terminals, is removed.

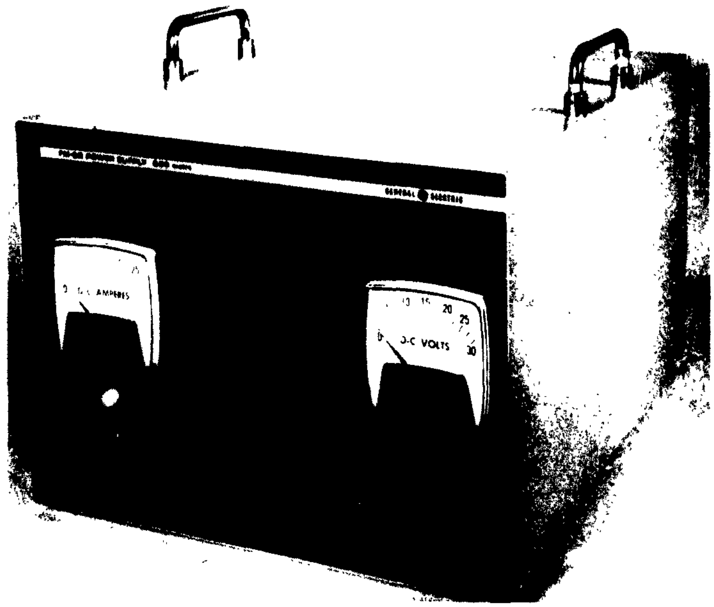

Figure 1a. Experimental Model of 600-Watt FM-SS Power Supply

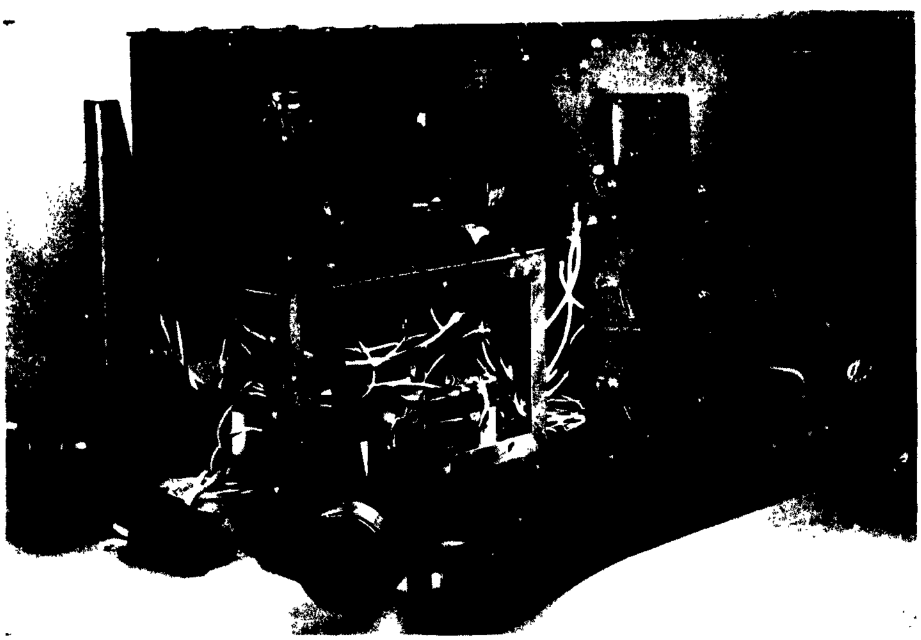

Figure 1b. Wired Chassis of 600-Watt FM-SS Power Supply

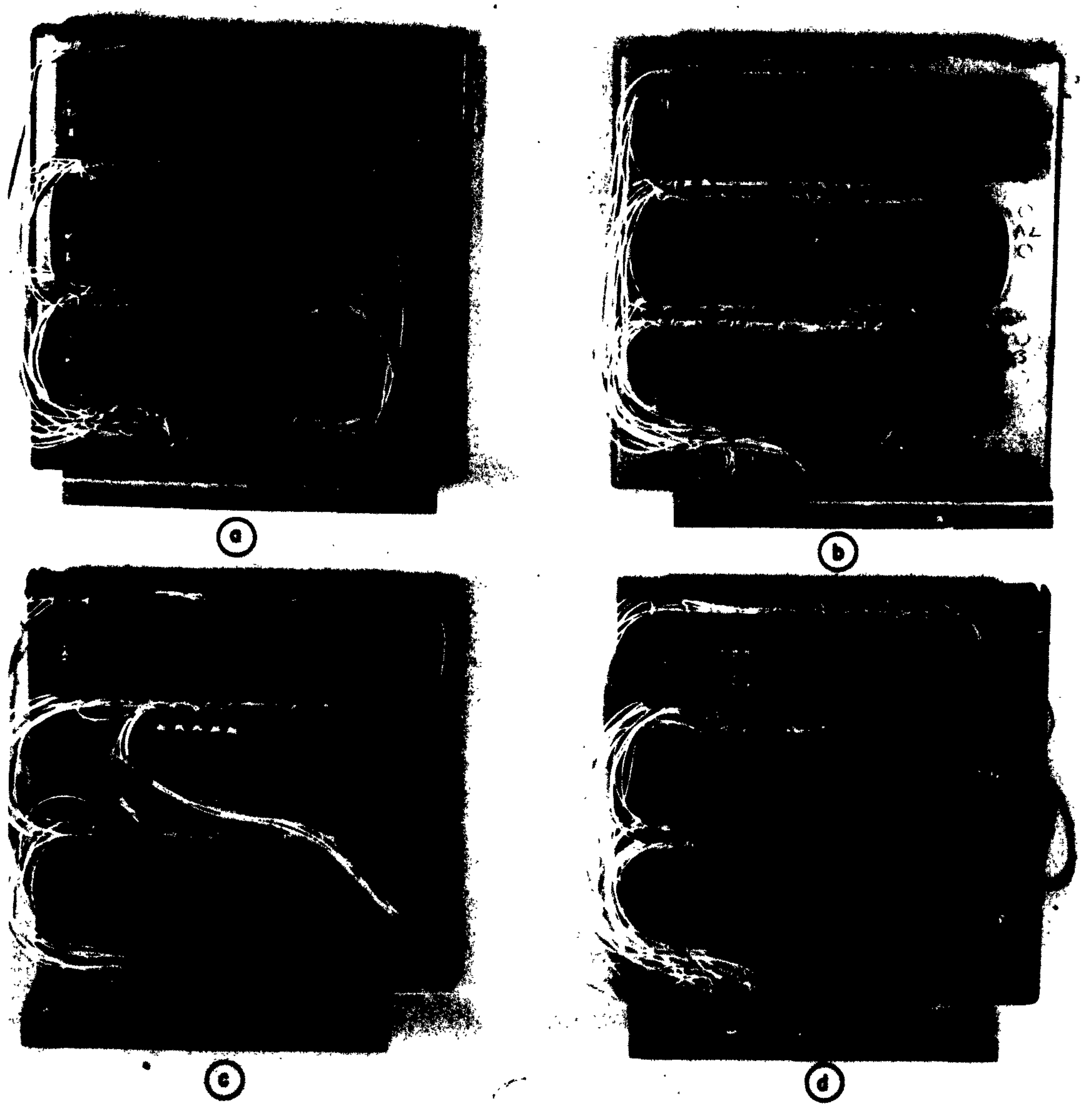

Figure 2. Control Circuitry of 600-Watt FM-SS Power Supply
a. Gating Circuit b. Protection Circuit
c. Integrator d. Internal Power Supply

III. CONFERENCES

One conference was held in Ithaca on 30 March 1962. USAERDL was represented by F. Wrublewski and W. Dudley. The Applied Physics unit of the Advanced Electronics Center was represented by C.G. Schnorr and F.C. Schwarz. Status of work was discussed with reference to a breadboard model, as described in this report, electric schematics, and mechanical diagrams. Packaging techniques were discussed using models of related work.

IV. FACTUAL DATA

A. Control Circuit Functions

The block diagram of a closed loop voltage regulator is shown in Figure 3. An FM-SS power modulator[1] serves as inverter-amplifier in this system. A more detailed functional block diagram of the same system is shown in Figure 4.

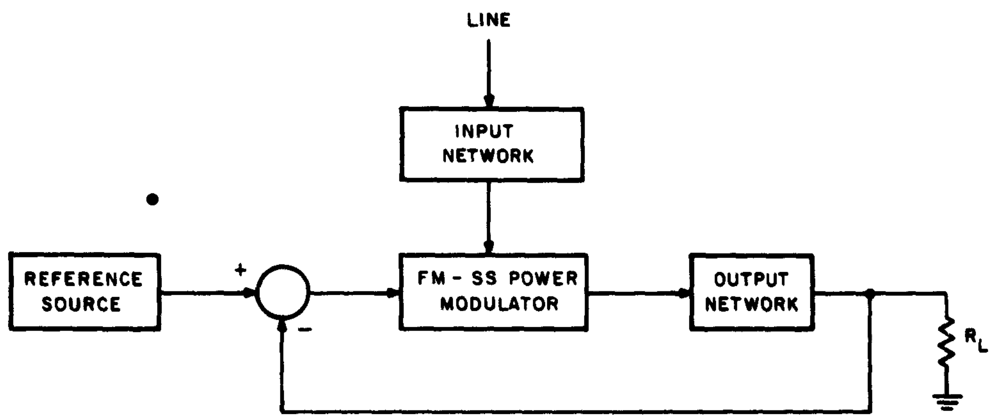

Figure 3. Summary Block Diagram of System

Input and output networks consist essentially of rectifier arrangements followed by L-type LC filters. The input network provides full-wave rectification and coarse filtering of the sinusoidally alternating single-phase supply source. A dc potential with a ripple of about 10 percent amplitude appears at the output terminals of this filter which form the input to the power modulator. The reference potential of this dc voltage oscillates, with respect to ground, in a half-wave fashion of the sinusoid of the supply source. The reference potential of the input circuit of the power modulator follows the same motions with respect to ground; the output terminals of the power modulator are referenced with respect to ground due to the isolating function of

an (HF) output transformer. The output network rectifies the pulsating and alternating current flow as emerging from the power modulator, and filters both the low and high frequency content of this power pulse train. The power modulator, being self-stabilizing, provides an appropriate output potential despite variations in supply voltage, loading, or variations in ambient conditions, and the feedback loop provides correction of deviations of the output voltage versus reference voltage, primarily due to the resistive voltage drop in the output inductor.

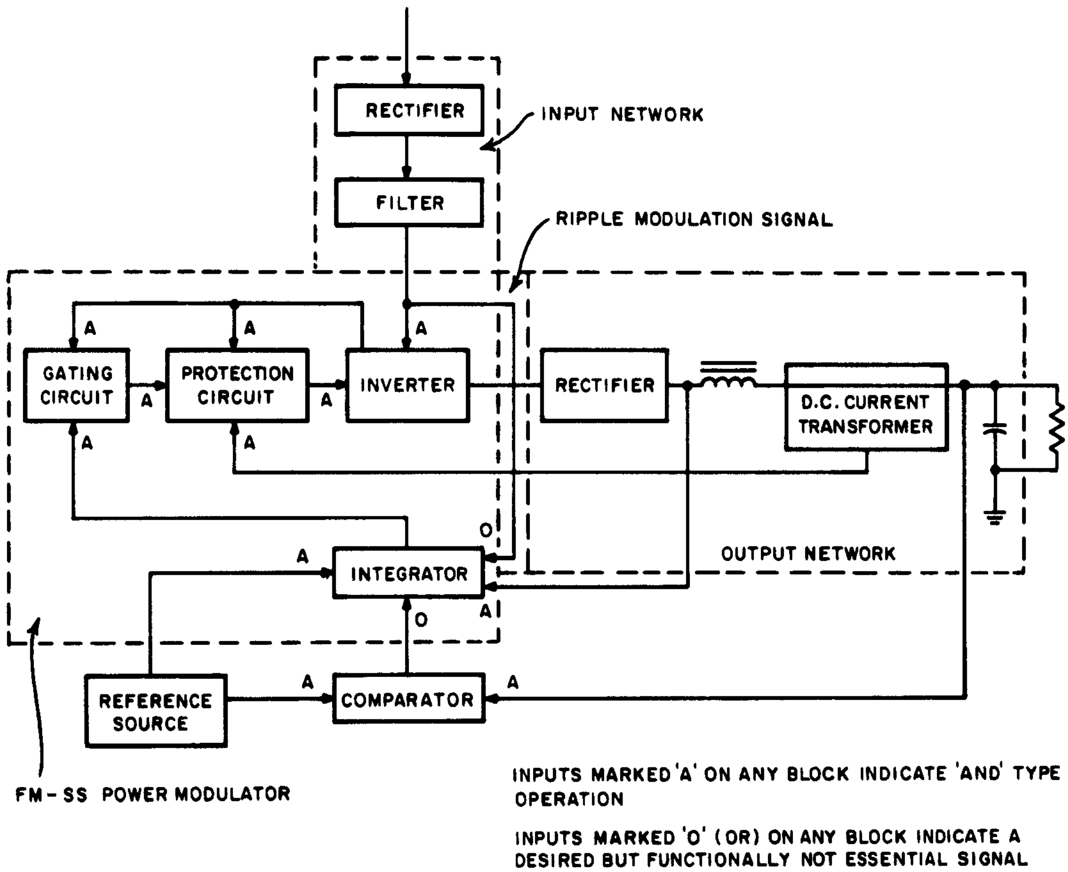

Figure 4. Functional Block Diagram of System

The mode of operation of the power circuit of the self-stabilizing power modulator is described in the pertinent progress reports[1,2] and certain features of the control circuitry will be highlighted here. The power circuit, incorporated in the experimental models and pertinent to this work, is shown in Figure 5. One pair of controlled rectifiers, CR1 and CR2, perform the basic inverter operation, while the other pair, CR11 and CR22, are used to attain parallel operation of capacitors C1 and C11 for loads in excess of 50 percent of the nominal load.

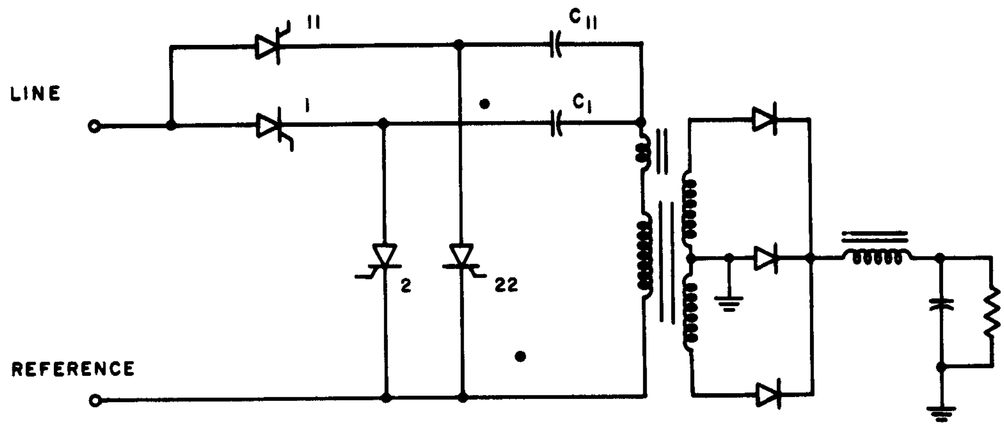

Figure 5. Power Circuit

The control circuitry associated with the power circuit (Figure 5) serves one purpose: to provide the firing signals on the gate terminals of the controlled rectifiers at the proper time. No other operation of the control circuit on the power modulator is required or provided for.

This firing of the controlled rectifiers is subject to a number of conditions:

1) The proper output voltage should be maintained with respect to the desired dc level and its ac ripple

2) Capacitor C11 is parallelled with capacitor C1 with appropriate current demand, and disengaged when not needed

3) No controlled rectifier can be fired if any other rectifier would provide a short circuit from line to reference

4) Firing of controlled rectifiers will cease if an overload condition exists in the output circuit, and will resume when that condition vanishes.

Condition (1) is satisfied by the integrator operation, according to the functional philosophy discussed in Progress Report No. 1, though the ferromagnetic integrator is replaced by an electronic integrator.

Condition (2) is fulfilled by operation of the direct current transformer,[3] which generates information about magnitude of the load current to the protection circuit, which in turn effects firing of one pair, CR1 and CR2, or both pairs of controlled rectifiers.

Condition (3) is at present the responsibility of both the gating circuit and the protection circuit. It is one of the key functions of the control circuit, and has to be fulfilled under any conditions of operation, including sudden transient conditions associated with starting, step-load application or removal, short-circuiting and open-circuiting of the load terminals, and the recycling operations associated therewith.

Condition (4) is jointly carried out by the dc transformer and the gating circuit. At about 115 percent of the full nominal load current, the dc transformer sends a blocking signal into the gating circuit which interrupts operation of the system. After decay of the latter blocking signal and elapse of the other delays due to the preprogrammed starting sequence, the system will automatically recycle. It will continue to do so indefinitely until the overload is removed and normal operation is resumed, or the system is manually turned off.

B. Control System Components

1. The Gating Circuit

Operation of the gating circuit is described with reference to Figure 6 which shows one-half of the gating circuit in block diagram form. The bistable multivibrator governs the system as each change of its state activates one of the firing pulse generators, which in turn fires the controlled rectifiers via the protection circuit and initiates the individual cycles of the power system.

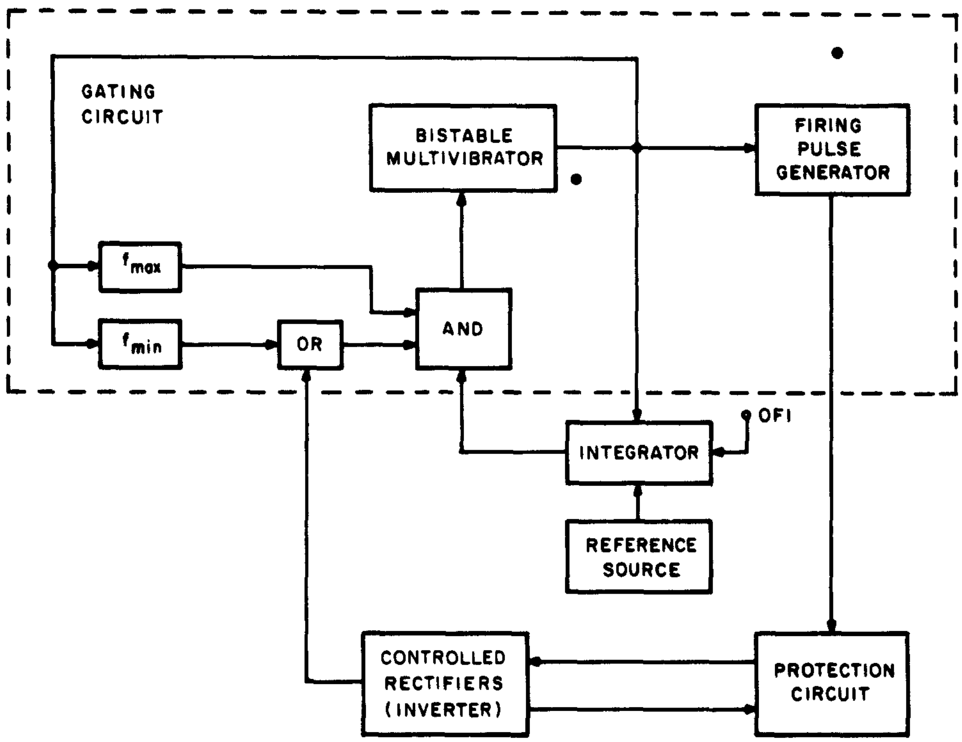

Figure 6. Gating Circuit (one-half) Block Diagram and Its Connections to the System

The integrator, which is also operated by this bistable multivibrator, absorbs information from the reference source and the output filter input (OFI) wave according to the functional philosophy of this system.[1] The completion of this process for one

cycle is indicated by emission of a trigger signal that should activate the multivibrator. However, this trigger signal has to be cleared first by an AND gate, which guarantees certain safeguards for proper operation, especially under transient conditions. The boxes marked f_{max} and f_{min} indicate unsymmetrical RC circuits, which are again driven by the bistable multivibrator and will emit clear signals to the AND gate with a certain delay after the bistable multivibrator has "flipped." These delays are implemented so that f_{max} will clear the AND gate within the shortest period T_0 that is permissible for safe operation of the power circuit, as it will limit the frequency of operation to a maximum, i.e., f_{max}. Conversely f_{min} will clear the AND gate, via OR, after a time interval that corresponds to the longest period T_0 that is permissible for safe operation of the power circuit, or it will limit the frequency of operation to a minimum, i.e., f_{min}.

All three inputs to the AND gate have to be energized to clear a trigger signal to the multivibrator. When the power system is at rest, and the entire system is energized, there will be no voltage wave on the input terminals to the output filter and, in the absence of an AND gate, the integrator will tend to oscillate at its top speed, when directly connected to the bistable multivibrator. The rapid succession of cycles at a speed of several hundred kilocycles, which include operation of the multivibrator, generates a fast train of firing pulses that try to reach the gates of the controlled rectifiers. Because of the endeavors of the protection circuit to process the information returned from the inverter, and its efforts to reject this irregular succession of pulses, an error hazard occurs due to the short but finite switching times of the control pulse circuits. This is compounded by the presence of starter circuit features which are exempt from the formal rigors of logic switching.

It is now evident that both RC controls, f_{max} and f_{min}, have to clear the AND gate in the absence of an inverter signal on the OR gate, because the integrator signal will be "waiting" at the AND gate entrance, as the integrator cannot freely oscillate, being deprived of access to the multivibrator, which in turn operates the integrator. Since f_{max} will clear the AND gate first, f_{min} exerts the critical gate control function, thus permitting the bistable multivibrator its slowest mode of operation. This operation will actuate the firing pulse generators at a moderate speed, which in turn will get the power system started. As soon as the first cycle is initiated, OFI transmits information to the integrator and immediately slows down its tendency of runaway operation. Concurrently a clear signal appears on the OR gate that is emitted by the inverter as soon as any of the controlled rectifiers reaches a turned-off (back-biased) position. Operation of the AND gate by the f_{min} delay is now superseded by inverter signals which carry the information of accomplished controlled rectifier turnoff, and permit the AND gate to clear the integrator trigger without delay at a repetition rate that exceeds f_{min}. The frequency of operation is now solely determined by the integrator, as necessary for proper operation. However, f_{max} imposes another limitation on the speed of operation, which only becomes effective under certain transient conditions, like short-circuited output terminals, recycling of the system, etc., but is otherwise not apparent.

The functional philosophy of the protection circuit is discussed in the pertinent progress reports,[1, 2] and has remained unaltered, except for certain features of logic associated with operation of controlled rectifiers in parallel pairs.

The gating circuit has usurped some of the functions of the protection circuit, because it senses the turnoff of controlled rectifiers and clears the integrator signals accordingly. This duplication of effort is an outgrowth of the chronological process of development. The protection circuit was maintained in addition to the gating circuit in the experimental models, as certain problems concerning the parallel operation of two pairs of controlled rectifiers screened by the gating circuit only have not been appropriately investigated, while the already expanded effort of design and construction did not warrant its elimination.

2. The Integrator

The functional philosophy of the integrator operation was discussed before.[1] Ferromagnetic integrators (saturable reactors) were used in that discussion, and the physical shortcomings of these integrators were analyzed subsequently.[2]

The ferromagnetic integrators absorb electric power (watts) in their nonsaturated state, and can be used to meter volt-seconds integration, as long as an essentially linear relationship to the magnetizing current is tacitly assumed. The character of ferromagnetic integrator operation in a frequency-modulated system does not permit that assumption, due to transient phenomena at the fringes of the periods, which occur at a varying repetition rate.

Another physical implementation of a linear integrator was sought for this purpose, that would actually integrate volt-seconds, demonstrate a minimum of transient phenomena at the fringes of periods, and require no further limiting assumptions. One further requirement was established: the integrator had to be virtually insensitive to variations of circuit parameters due to physical shortcomings of components, especially under variations of ambient temperature, and aging effects.

The classical electrical integration component--the common capacitor--was chosen for that purpose, and the associated network appropriately adapted. The defining capacitor equation

$$\Delta V = \frac{1}{C}\,\Delta Q = \frac{1}{C}\int_{t_1}^{t_2} i(t)\,dt \tag{1}$$

establishes one premise for the integrator network: The voltages in question that should be integrated have to be transformed into currents of equal waveshape and proportional magnitude.

This is implemented by establishing current sources that are the duals of the former voltage sources. These current sources I_R, I_0, and $i_0(t)$ are the duals of the voltages E_R, E_0, and $e_0(t)$ in question. They operate into a capacitor C as shown in Figure 7, and are gated by switches S1 and S2 as shown. These switches close and open in alternating fashion. The voltage on capacitor C is governed by the equation

$$\int_0^{T_{0k}} I_R\,dt - \int_{T_{0k}}^{T_{0k+1}} I_0\,dt + \int_{T_{0k}}^{T_{0k+1}} i_0(t)\,dt = 0 \tag{2}$$

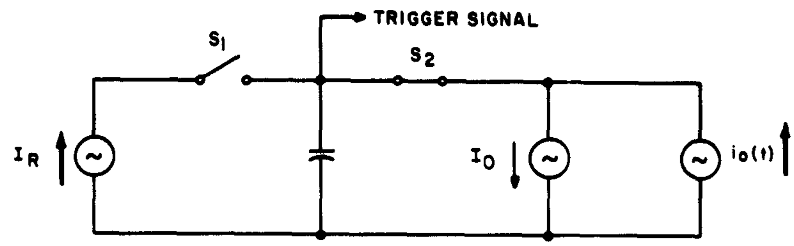

Figure 7. Ampere-Seconds Integrator

under conditions of cyclic stability is $T_{0k} = T_{0k+1}$ so that for constant (reference) I_R and I_0, this relation is rewritten as

$$I_0 - I_R = \frac{1}{T_{0k}} \int_0^{T_{0k}} i(t)\,dt = \frac{I}{T_{0k}} \tag{3}$$

where I is the dual integral of the inverter output voltage as defined before.[1] The voltage wave on capacitor C could be represented by a symmetrical triangular wave, if the current source i(t) were absent. A wave that resembles that of a triangle results in the presence of the latter, having the characteristic sharp corners, whenever switches S1 and S2 alternate. Either of the two extremities in capacitor voltage can be chosen for triggering purposes to link this integrator with the general control system. The lower voltage bound was chosen for the present application and a gate triggered via a voltage-threshold sensing zener diode. The switches S1 and S2 are operated by the bistable multivibrator that governs the system. This reciprocal interrelationship between the overall control system and the integrator was described previously in this report. Two of these integrators are in the system, each one associated with an inverter half, as analogous to the operation of ferromagnetic integrators (saturable reactors).

It should be noted that a charge accumulated on capacitor C that is proportional to the period of one cycle T_{0k} rather than a fixed threshold voltage is used as reference write-in for comparison with the readout process. The purpose of this technique is multifold. For one it permits the implementation of the functional philosophy of the FM-SS system.[1] If, furthermore, the character of dualization of voltage sources, and the physical implementation of switches is realized under conditions that can be called equal for all functions concerned, then an electrical symmetry of operation is achieved, that renders this integration insensitive to physical shortcomings, due to variations in ambient temperature, aging of components, etc. The dualization of all voltage sources is implemented by one and the same physical device, and both switches, S1 and S2, are implemented by the operation of one transistor in conjunction with similar diode gates. These techniques transform a functionally two-port network (Figure 8) into a single-port network with one alternating switch S1, 2 at one input terminal. This one-port character of the integrator network and its bilateral virtual electrical symmetry are devised to eliminate the effects of time-varying properties of components by functional design (autocompensation) rather than conventional compensation.

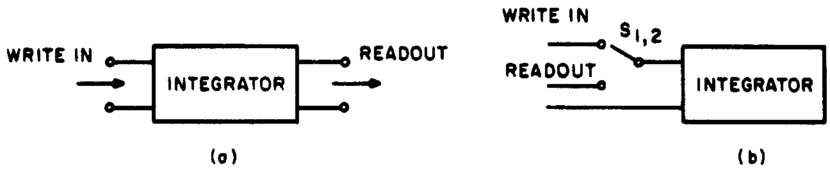

Figure 8. Integrator as (a) Two-Port and (b) One-Port Network

The ferromagnetic integrator of a conventional magnetic amplifier can be characterized as a two-port network with a write-in signal from a current source, and a readout operation from a voltage source. The accuracy of this amplifier hinges on the volt-ampere characteristic of the ferromagnetic integrator, which is subject to variations in temperature of the saturable cores, their history of mechanical strains, frequency of operation, etc. These variations are as a rule countered by thermistor control of the write-in current. This technique is limited by the inequality of the physical properties of saturable reactor materials and thermistor materials respectively. The latter difficulty is overcome, when using the autocompensation of the saturable material itself.[4] This would not, however, solve the discussed problems of ferromagnatic integrators when used in frequency-modulated systems.

3. The Direct-Current Transformer

The direct-current transformer senses the loading conditions, and generates corresponding signals. These signals are absorbed by the control circuit which in turn will provide the appropriate system functions as set forth on page 9.

The no-load condition is met by a dynamic dummy load,[2] which provides a 20-percent loading of the system under the condition of no external load, and disconnects itself automatically and gradually with increasing loading until it is completely disengaged at about 25-percent loading of the system. All functions pertaining to loading conditions are governed by the direct current transformer. This saturable reactor device[3] senses the load current flowing into the output terminals and generates a signal level quasi-square-wave at about 1 kc, whose volt-second content is ideally linearly proportional to the load current. The maximum amplitude of this square wave is 30 volts for the present application. This variable ac wave is fed into rectifiers and filters and provides the control signals for operation of the dummy load, parallel operation of C1 and C11 (Figure 4), and the overload protection function. The operation of the direct-current transformer is illustrated in Figure 9. Dummy load transistor DT is normally biased ON and this connects the dummy load resistor DR between the output terminals. The respective rectified and filtered output of the direct current transformer directs a negative dc signal to the base of DT which gradually overrides the ON bias with increasing load current.

A similar condition exists in the protection circuit where the firing pulses to the second pair of controlled rectifiers CR11 and CR22 are blocked by an AND gate (not shown in Figure 9), that will clear these firing pulses only in the presence of a satisfactory direct current transformer signal. The latter is set to occur at about 50-percent loading and thus the additional series capacitor C11 is added to capacitor C1, while it is again released whenever loading falls below that limit.[2] An appropriate hysteresis avoids conditions of undue oscillations.

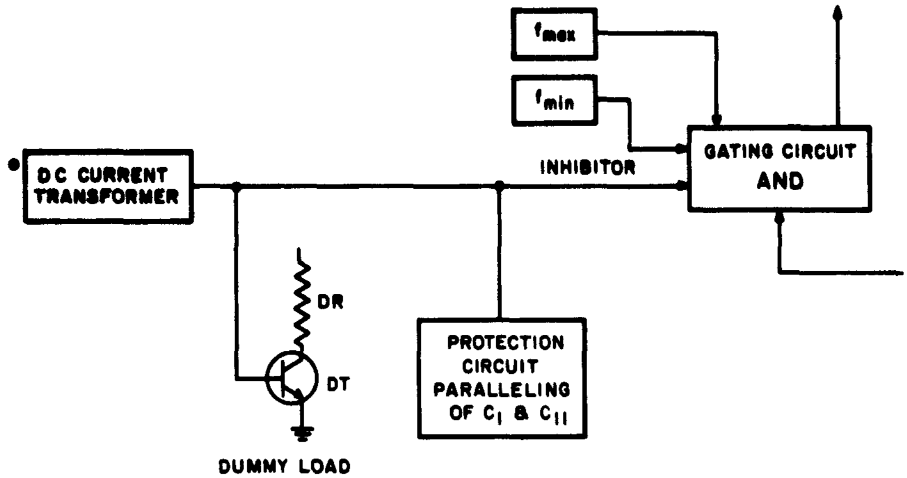

Figure 9. Schematic of Direct-Current Transformer Operation

Overload protection was discussed before, and its operation may become evident with reference to Figure 9. The inhibitor signal applied to the critical AND gate of the gating circuit brings the system to a standstill for lack of firing pulses. This inhibiting signal itself will, however, vanish after some provided delay, and the system will recycle after clearance of that AND gate; i.e., initiate its ordinary starting progress. With continued overload, the system goes into slow oscillation, with a several-hundred-millisecond period which it will keep up without damaging effect until the overload, which may consist of a short-circuited output, is removed.

4. Internal Power Supply

Power for operation of the control circuits is provided by an internal power supply (IPS). The IPS contains an ordinary saturable-reactor-operated square wave inverter, operating at about 1 kc from a dc source of approximately 19 volts, at a power level of about 4 watts. It provides the filtered dc voltages as required, an ac source for operation of the direct-current transformer, and power for the dc reference source. Power for the IPS is derived from the output terminals of the system and is thus considerably ripple-free and regulated. A power zener diode in parallel with the IPS input adds further independence of variations in output voltage setting.

In the absence of a system output voltage the IPS is started by a considerably underdesigned auxiliary power supply (APS) which is highly inefficient and the effects of whose output ripple are noticeable in the performance of the power system. It will however start the system safely, and this is its purpose. The system output voltage supplies its power to the IPS as soon as it comes into existance, and the APS is turned off for the remainder of that operation cycle. This is implemented by a simple relay switch (Figure 10) in series with the ac supply line which opens as soon as the dc supply output voltage exists. The APS will operate for about one second or less when the equipment is turned on, which accounts for its intended low quality for weight economy. However, the APS will supply continued power to the IPS whenever

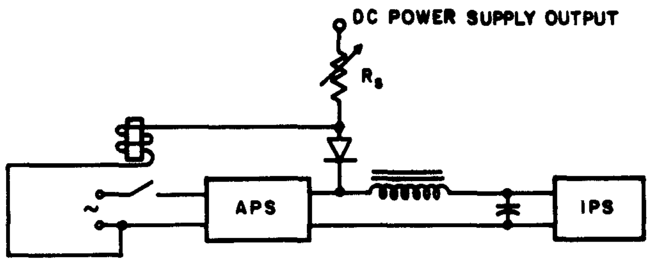

Figure 10. Internal Power Supply IPS and Its Starter Circuit

the system is substantially overloaded, and no output voltage exists to take the APS function over. In that case the APS will operate continuously without damaging effects to itself and at a poor efficiency (tolerable under these conditions) until normal operation is resumed.

5. Reference Source and Comparator

The reference source consists of a conventional temperature-compensated reference amplifier RA for the positive voltages E_R and E_C, as shown in Figure 11. E_R and E_0 are the voltage reference sources required for the integrator operation.[1] E_C is the comparator reference source for the feedback network and its voltage has the nominal magnitude of the system output voltage. E_R and E_C vary inversely at a certain ratio consistent with the functional philosophy of this system, while E_0 is fixed. It is, furthermore, necessary to vary R_S (Figure 10) concurrently with E_R and E_C, as the system output voltage changes and this variation has to be absorbed in order not to oversupply the IPS. This concurrent variation of E_R, E_C, and R_S is

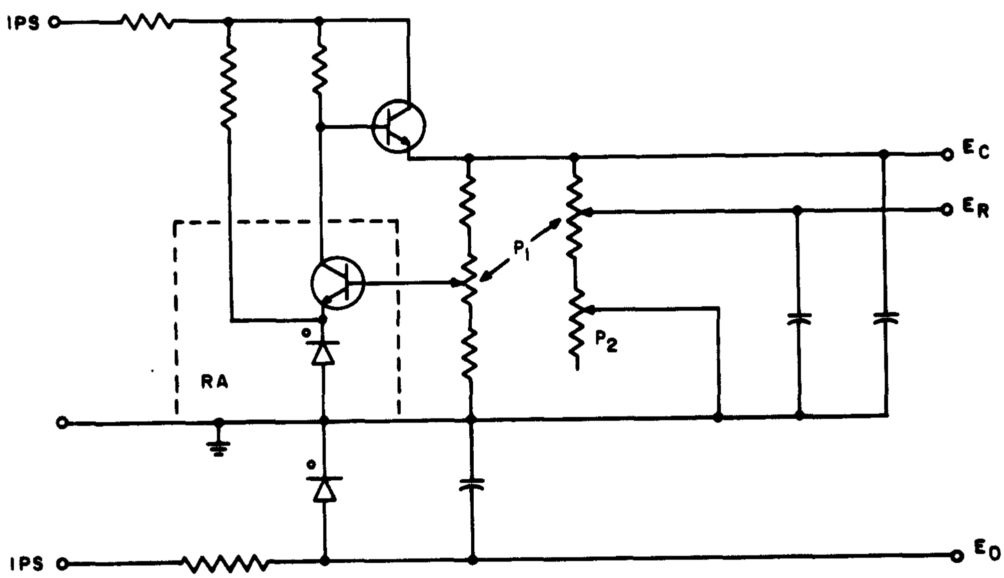

Figure 11. Reference Source

implemented by ganging three potentiometers on one shaft P_1 which varies the three resistances or dividers in question (Figures 10 and 11) simultaneously in the desired fashion. Potentiometer P_2 in series with the E_R divider provides the proper dynamic ratio (difference of slope of variation per radian of angular rotation) between E_R and E_C, and is locked after adjustment. The shaft of P_1 is brought out through the front panel for setting the output voltage.

The comparator is implemented by a conventional ring modulator which senses the dc error between reference E_C and the system output voltage, amplifies it and superimposes that error in ac form on the dc reference voltage, appearing as a square wave ripple. The ring modulator is operated by the multivibrator in the gating circuit and thus in step with the integrator. This synchronism makes the above-mentioned ac signal appear as a dc signal to the integrator and permits an ac error signal detection without (filter) delay and introduction of errors due to rectification.

Figure 12 shows the feed-forward transformer FF secondary windings[1] in series with the comparator output. They carry the relatively slow signal of the sinusoidal line ripple, which is essentially in phase opposition to the actual line ripple. Unlike the output voltage error signal, this signal transmits no relative dc component, as it is not in step with the bistable multivibrator which governs the system. It will not affect the dc regulation of the system, and it is instrumental in suppressing the line ripple.

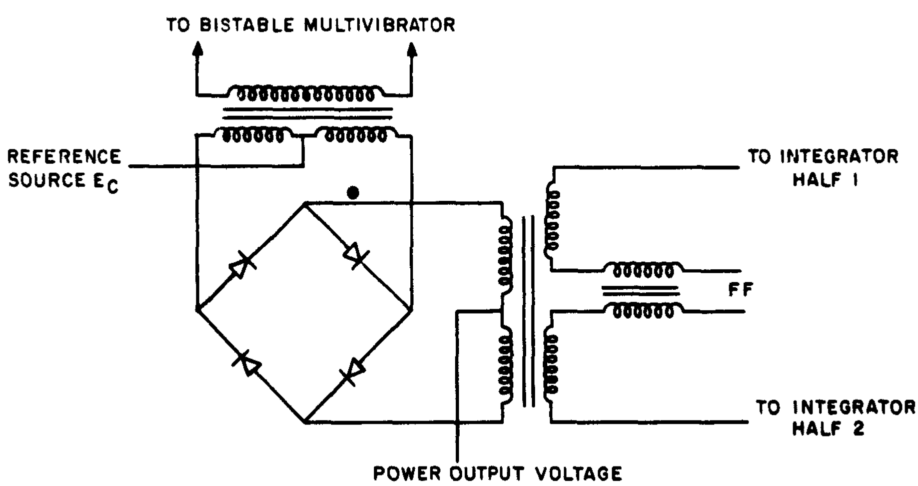

Figure 12. Ring Modulator and Its Connections to the Control System. Secondary Windings of Feed-Forward Transformer FF for Ripple Suppression Are Included[1]

C. Input Circuit Features

The system operates from a 115 v or a 230 v ac 50/60/400 cps single-phase line respectively. It is designed to operate for the lowest line frequency, 47 cps. The inverter operation as such is independent of the applied line frequency, except for some variations in active filtering effect. Any sensitivity to line frequency variations is vested in the dc filters, and they actually improve in performance with increasing line frequencies.

The change from one input voltage level to another requires that the input filter and the primary circuit of the inverter be rewired so that component ratings correspond to the input voltage level. Split windings on the wire-wound components permit their series/parallel arrangement for proper adjustment to the voltage level in question. This is complemented by an analogous arrangement of half-size capacitors, as shown in Figure 13. No further system modifications are needed, once the input circuit is rewired, except for certain auxiliary circuitry. The secondary power circuit, and the control circuit "do not know" from what line voltage the system operates, once the indicated connections are properly established. The semiconductors in the input circuit are rated according to the higher voltage level, as are the damping circuits associated with them. The losses of the latter at the higher voltage level are counterbalanced by a better efficiency of the semiconductors with the correspondingly lower load currents.

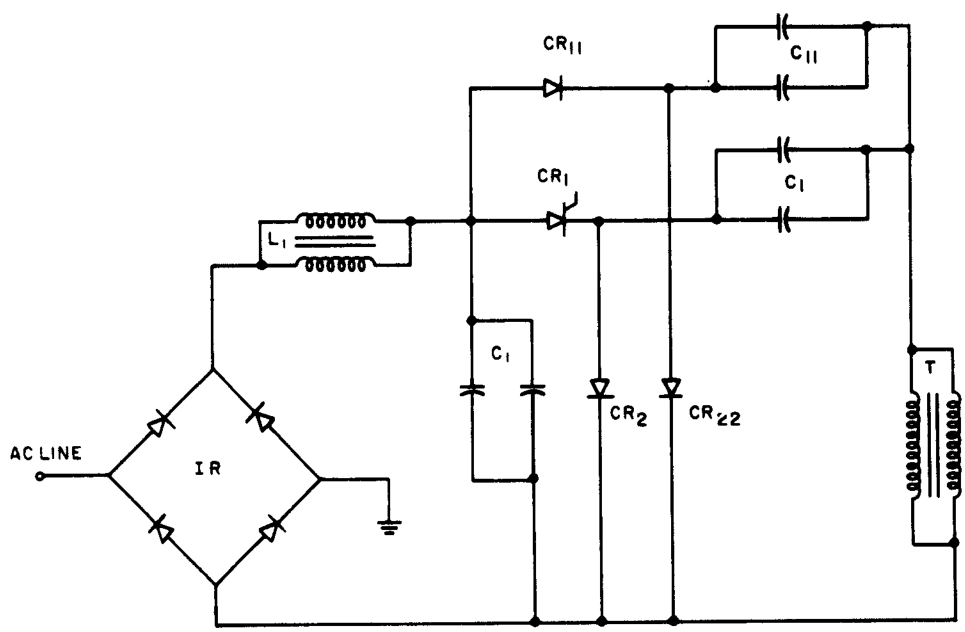

Figure 13. Input Rectifier, Filter, and Primary Circuit of FM-SS Power Supply for Two Input Voltage-Level Operation from Single-Phase ac Line

The problem of how to guarantee that the multivoltage input equipment is properly set before it is connected to the line has a long tradition of hapless events. The tasks of (a) unmistaken identification of the available line power, and (b) proper adjustment of the equipment to it before connection, invite human error, notwithstanding the level of competence of personnel.

The final answer to this problem will lie in a completely automatic adaptation of the system to the given multitude of line conditions. This was briefly studied, and found readily feasible, though a certain effort is required. Simple voltage discriminators could actuate appropriately latching relays in a sequence of safe assumptions and thus implement the principle. When the specifications of available relays were studied and relay designers consulted, it was found that relays with larger contact current ratings are apparently not designed for economical operation. Therefore, auxiliary circuitry will have to be devised to that end, or special control contact connections added to (magnetic) latching relays. Since the necessary effort could not be reconciled with the framework of the contract, a compromise between safety and cost was sought.

These systems are provided with two cables, each one terminating in a line plug and a multipin connector on either end. The line plug fits the receptacle of a given ac line as conventional in the United States. The multipin connectors that fit one of their counterparts on the equipment have different key ways that make confusion physically impossible, i.e., the power supplied by a given type of line outlet will be fed into the right connector on the equipment. This multipin connector serves a dual purpose. It feeds the power from the line into the equipment and it rewires the system according to its corresponding input voltage by interconnecting the appropriate network nodes; this is implemented by wiring leads from the circuit points in question to the connector pins on the equipment, and "wiring" these points by jumpers between the corresponding "empty" pins on the cable connector. As long as the proper line plug is connected to the intended supply source, no human error is possible, since the equipment is adapted to that line voltage by use of the corresponding cable. If, however, the line plug is rewired, or replaced by another type plug (as may be necessary abroad) then that safeguard is removed, and the tradition of hapless events may be continued.

The present arrangement should suffice for the experimental models. Small physical size, low contact resistance, and low cost are agreeable byproducts of improved safety. The numerous load-current-carrying wires needed for that purpose and their interconnections posed a sizeable construction problem and constitute a price paid for the removal of the low-frequency input transformer.

Another consequence of the removal of the input transformer is the fact that the reference potential of the input circuit as shown in Figure 13 oscillates with a half-wave rectifier waveform with respect to ground, as this appeared the only way to derive full-wave rectified power from a single-ended ac line. This type of operation is of relatively little theoretical significance, as the inverter transformer provides the necessary isolation between source and load circuits. However, a number of problems did arise from undesired cross couplings in the control circuits, where signals

pertaining to either of the two reference levels have to coexist at times in close relation.

D. Results

The main purpose of work under this contract is the development of techniques that permit a substantial reduction of weight and physical size of ac to dc power supplies, when compared to equivalent conventional type equipment. While this is the asserted goal, "it is tacitly implied that the other essential conditions will be met concurrently; these other conditions often present a more difficult problem than the goal of prime consideration."[5]

The weight of a conventional dc power supply is largely due to: (1) the power transformer and (2) its dc filters. The weight of power transformers is reduced by the use of inversion techniques in the kilocycle range, which do not alleviate the filtering problem, whose severity is expressed by the required line ripple attenuation, at the given line frequency. As the efficiency of a power supply enters into the weight consideration, it may be appropriate to express these interrelations in the form of a figure of merit.

$$F = \frac{aP}{\omega^2 (1 - \mathrm{eff}) W_T} \cdot \frac{\Delta T_{max}}{25} \tag{4}$$

where

a = input ripple percentage/output ripple percentage

P = dc output power

$\omega = \begin{cases} > 1 \text{ the supply line frequency} \\ < 1;\ \text{set } \omega = 1 \text{ (including dc)} \end{cases}$

eff = overall efficiency of the power supply in fractions of unity

W_T = the total equipment weight in lb

ΔT_{max} = maximum ambient temperature deviation from standard room temperature of 25°C

It is readily seen that if any of the factors were removed in relation (4), then the figure of merit F would become relatively meaningless, unless a standard output voltage ripple with operation from a commercial ac source is tacitly assumed, and no efficiency of operation or ambient temperature range specified.

The problem of dc filter weight reduction was solved by a technique of dynamic modulation.[1] The FM-SS power modulator "sees" its input voltage ripple which appears on the output terminals of the input filter as a slow varying dc voltage variation and opposes it by its regulatory mechanism. An AM countereffect to the line ripple is produced by appropriate frequency modulation of successive pulses of energy. The volt-seconds per second carried by this pulse train is ideally a constant but the energy of the individual pulses per duration of period is not, as their rms contents differ.

This residual periodical time variation in energy sustains the output voltage ripple. It is countered by further amplification of the ripple-opposing action of the inverter by appropriate control techniques,[1] which render the inverter output voltage rms content linearly proportional to the time-varying periods, and thus a constant per unit of time when considered over each closed (HF) cycle.

It is believed that one important prerequisite to the application of this active filtering technique is the Type 1 control system operation of the self-stabilizing inverters which respond immediately to changing conditions in supply line voltage or loading.[6] That is, the (half-cycle) delay found in conventional magnetic amplifiers, compounded by the error reaction signal delay due to the output filter would add considerably to functional difficulties and stability problems.

The active filtering effect of the FM-SS power modulator is attained with no addition of power components in number or size, and thus constitutes a net gain in weight reduction. A certain complexity of the control circuitry common to inversion techniques is the price paid for this weight reduction; other advantages that evolved as byproducts of this research program are discussed with other topics in this report.

Figure 14 shows the output voltage ripple of the 260-watt experimental model as a function of loading and variations of input voltage. Except for isolated data, the output voltage ripple is below 0.37 percent peak-to-peak (35 mv rms), and its median is near 0.27 percent peak-to-peak (25 mv rms). Isolated points with a ripple of 0.43 percent peak-to-peak (40 mv rms) are attributed to the fact that the average inverter frequency is near its design limits of maximum frequency f_{max} = 5 kc, and lacks the required additional fringing frequency band to allow for dynamic ripple-opposing frequency modulation. In other words, the ripple-suppressing mechanism is saturating (bottoming) under these conditions, and causes a partial loss of the active filtering effect.

This is readily seen by correlating the data in question with the corresponding recorded frequencies in Figure 15. The output voltage ripple is nevertheless well within the goals of this work requiring a maximum ripple of 0.5 percent peak-to-peak. This discussion intends to show the potential of this technique. Difficulties caused by physical shortcoming of components and undesired cross coupling effects had to be overcome, and there is room for further improvement in the light of gained experience.

A worst-case ripple attenuation of 1.34/0.0043 = 312 was attained with a passive dc filter, accounting for an attenuation of 84 at 120 cps filter frequency. A net active filtering effect of 3.72 is credited to the FM-SS inverter, with a commensurate reduction in filter size and weight. Elimination of the isolated data by removal of design limitations appears readily feasible. The active filtering effect a_{FM} rises then to

$$a_{FM} = 1.34/(0.0037)84 = 4.35$$

Further improvement by redesign of the ripple signal transmission should bring the output voltage ripple within the order of its present optimum at full load, with an active filtering effect a_{FM} of one order of magnitude.

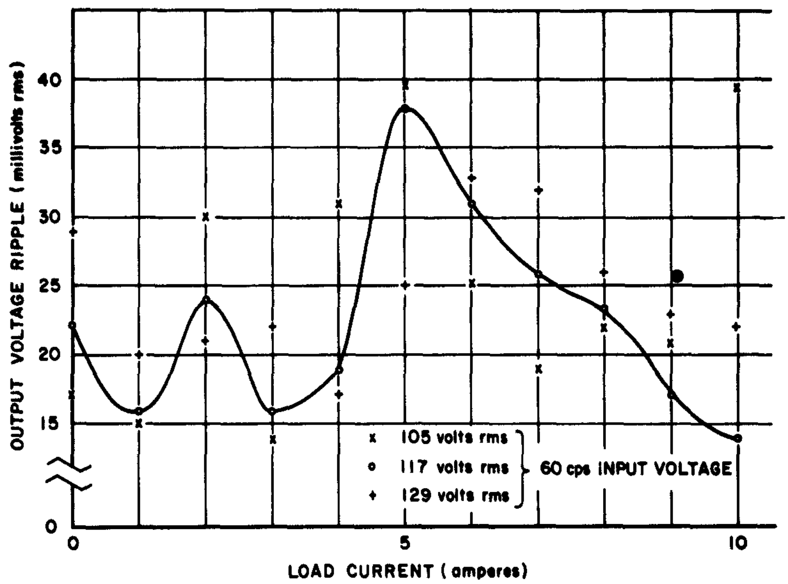

Figure 14. Output Voltage Ripple of 260-Watt FM-SS Power Supply

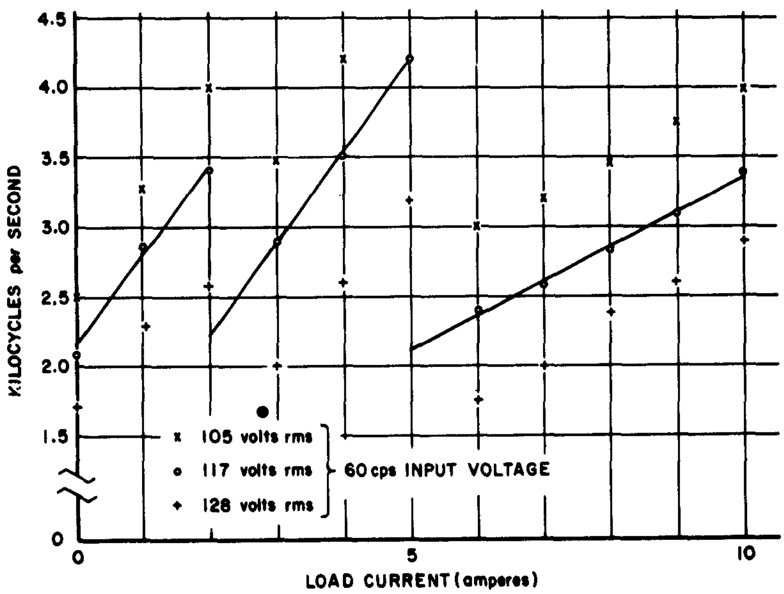

Figure 15. Operating Frequencies of 260-Watt FM-SS Power Supply

The present transformer and dc filter component weights for the 260 and 600-watt units are about 10 and 19 lb, while the remaining semiconductor and control circuit components amount to about 5 lb in each case. The mechanical structure is the same for both models and weighs 18 lb. The power transformers are (net weights of 1.2 and 2 lb respectively) relatively insignificant with respect to the power component weights; however, they are more than 60-percent overdesigned due to early release of specifications. Wire-wound components are carefully designed but are not optimized. A design improvement of the ripple signal transmission network, and an expected relaxation of the output voltage ripple requirements to one percent peak-to-peak should permit a substantial reduction of dc filter sizes.

Output voltage regulation of the 260-w model as a function of input voltage on loading is shown in Figure 16. The data as presented in Figure 16 show two spots of discontinuity in downward trend at load currents of 2 and 5 amperes. The downward trend with increasing loading is due to the resistive voltage drop in the output filter inductor, and consistent with the Type 0 regulation of the outer feedback loop, as seen from Figure 16. The discontinuities, just referred to, are due to the step changes in frequency over one octave as shown in Figure 15 which put a severe strain on the integrator accuracy. This is compounded by a number of fixed transistor rise and fall times in the control circuitry which are disproportional to the widely varying periods of cycles. Output voltage regulation is, however, well within specifications of ± one percent. The closeness of output voltage readings associated with a given load current and for various input voltage levels confirms the Type 1 control system character of the FM-SS inverter.

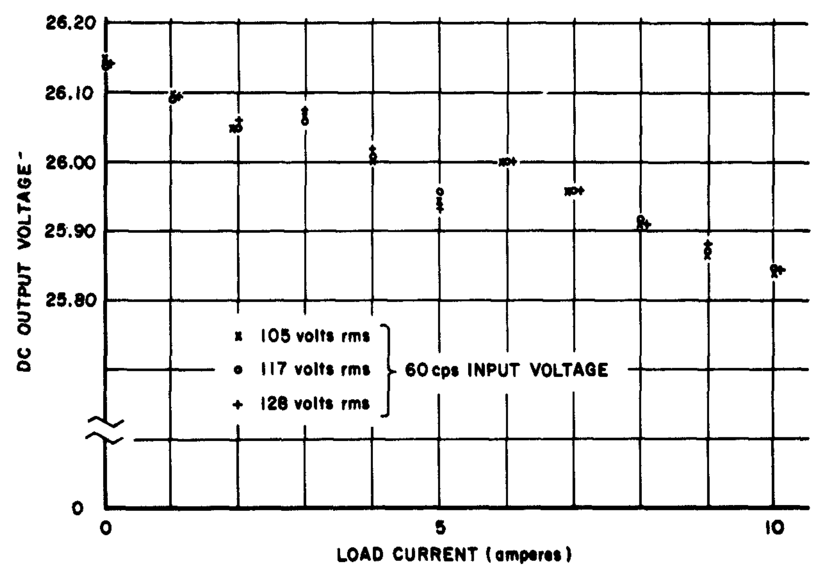

Figure 16. Output Voltage Regulation of 260-Watt FM-SS Power Supply

Output voltage variations are within ±0.62-percent limits. The outer feedback loop was designed for the smallest tolerable gain for the benefit of stability considerations. No investigation into the application of higher gains to attain higher accuracies was undertaken. Intentional introduction of a constant error per cycle into the integrator can flatten the output voltage regulation curve, as was verified by experiment. No such adjustment was applied, as it was felt that it would obscure aspects of the character of the system when still under study.

E. References

1. "Switch Modulation Techniques," Report No. 1, Contract No. DA 36-039-SC-87353, General Electric Co., Ithaca, N.Y., Nov. 1961.
2. "Switch Modulation Techniques," Report No. 2, Contract No. DA 36-039-SC-87353, General Electric Co., Ithaca, N.Y., Feb. 1962.
3. Buchhold, T., "DC Current Transformers and Magnetic Frequency Doublers," Technical Report No. 63, Ordnance Research and Development Division, Suboffice (Rocket), Fort Bliss, Texas, 1950.
4. Schwarz, F.C., "A Self-Adaptive Magnetic Voltage Stabilizer with 0.1% Output Voltage Regulation under Adverse Environmental Conditions," Technical Information Series Report R60ELC53, General Electric Company, Ithaca, N.Y., 1960.
5. Schwarz, F.C., "Switch Modulation Techniques in AC to DC Power Supplies," Proceedings of the 16th Annual Power Source Conference, May 1962.
6. Schwarz, F.C., "Switch Modulation Techniques in AC to DC Power Supplies, II," Proceedings of the 17th Annual Power Source Conference, May 1963.

V. CONCLUSIONS

The technical objectives of the program appear to be attained, as evaluation of the preliminary performance data and physical features show.

The two main causes of bulk and weight in a dc power supply - (1) the power transformer, and (2) the dc filter - were attacked by high power frequency inversion, and dynamic ripple suppression respectively. The power transformer was reduced to a point where it has become a secondary matter of consideration. The dc filter load was reduced by a factor in excess of three over the entire range of operation, with no penalty in efficiency.

Positively fail-safe SCR inverter operation was attained and verified, under adverse conditions of recurrent power interruption, compounded by arbitrary application of overload and short circuits to the output terminals. Automatic recycling reestablishes output power after return to normal loading conditions. The latter feature exceeds the program requirements that the power supply "shall not be damaged" by an overload.

Output voltage regulation and ripple appear well within requirements.

Physical size and weight of the nearly completed experimental models do not fully reflect the achieved functional advantages. They do not constitute optimum designs as pertinent design criteria evolved during the latter part of the program. Parallelism of development work and physical construction led to duplication of functions and anticipation of unnecessary safety margins, in addition to other minor complications. Use of the same mechanical structure with a weight of about 18 lb for both models, for reasons of economy, puts an undue weight burden on the 260-watt models. This is added to the fact that both models (260 and 600 w) use identical control circuit and auxiliary components with a total weight of about 5 lb. Present power component weights are about 10 lb for the 260-w model and 19 lb for the 600-w model. This brings the weight of the experimental models to 33 and 41 lb respectively, where the inadequate total weight ratio indicates a lack of weight-oriented design, as

referred to previously. Use of a similar mechanical structure of 18 lb weight is planned for a 1-kw dc power supply of the same type. It is expected to weigh less than 50 lb.

The FM-SS power modulator that was invented and reduced to practice under this program has been proven to permit construction of weight saving, reliable, and accurate power supplies.

VI. RECOMMENDATIONS

Further work should be directed toward:

1) Consolidation of the functional advantages of dc power supply systems that have been gained by:

a) A dc filtering technique that reduces substantially size and weight of dc filters with no penalty in power loss

b) A positively fail-safe inverter operation that secures reopening of controlled rectifiers on actually prevailing conditions, rather than a prediction, and operates, furthermore, without CR turnoff currents.

2) Exploitation of these advantages

3) Further functional system research and development.

A general review of control circuitry should lead to a proper integration of the system functions developed, and eliminate functional duplications that were due to development in successive steps. A reduction of the control circuits by about one-third is expected, with no penalty in present functional reliability of operation. Review and simplification of control circuitry could be associated with minor modification of the power circuits to reduce some of the burdens of the first. A reduction of the auxiliary circuitry, including the internal power supplies, will be accomplished by a simplification of the overall control circuitry. Further study of the developed ripple suppression technique should lead to a flatter transfer characteristic of that suppressor, and secure an understanding of secondary phenomena associated with this function.

A more concise design of power and control circuits will be possible since the results of present work and of further studies are available. Design of wire-wound components should be carried out within closer design limits to permit optimization with respect to weight and size. A design review of dc filters in that light appears significant, since they contribute more than 50 percent to the overall weight of the present models.

Further innovations in the power system design should simplify the system itself. A self-adaptive mechanism of impedance matching of the series inverter to the load appears as one objective of interest that should reflect favorably on the volume of control circuitry needed. Another substantial improvement would consist of the elimination of the dc input rectifier and filter, and operation of a modified FM-SS power modulator as ac converter. More compact dc filter design and reduction of the number of power components would constitute an appreciable advantage. The advantages that can be gained with respect to stability appear to be of more significance as the number of filter sections, including the inverter's "active filter section," is reduced.

Operation of this system as a constant current source appears feasible. A current proportional to load current could be fed into the integrator (without dualization) and the integrator would integrate untransformed ampere-seconds instead of the present volt-seconds. The remainder of the system would not even "know" that it is operating as a constant current source, and would function internally in an unaltered fashion.

The recommendations are discussed in more detailed form in the Proposal for the Second Phase of Switch Modulation Techniques, prepared for the U.S. Army Electronics Materiel Agency, Fort Monmouth, New Jersey, by the Advanced Electronics Center of the General Electric Company in Ithaca, New York, 1962.

VII. IDENTIFICATION OF PERSONNEL

E. W. Manteuffel

Dr. Manteuffel was awarded the Diploma-Ing. in 1929 and the Dr.-Ing. (DSC) degree in 1941 by the University of Darmstadt, Germany.

He was an instructor in the Institute for Electric Machines, University of Darmstadt, in 1930 and 1931, an Assistant Professor in the Institute for Electric Power Transmission and Power Plants from 1931 to 1934, and Assistant Professor in the in the Institute for Electric Power Plants and Electrical Apparatus from 1934 to 1936, where he solved several theoretical and experimental problems on ac commutator generators and pseudoharmonic oscillations, and designed special electric devices (e.g., continuously regulated transformer).

Dr. Manteuffel was a Development Engineer at Brown Boveri and Cie, A. G. Mannheim, Germany, where he developed and tested electrical apparatus and automatic control systems for electric locomotives and multiple unit motor-car trains from 1936 to 1940. During the period from 1940 to 1945, he was chief of the Development Laboratory for electrical apparatus and control systems for electric locomotives and chief of the Design Section for electrical apparatus for locomotives, streetcars, and trolley buses. During this time he developed a novel system for regenerative ac braking of electric locomotives, different solid state regulators employing magnetic amplifiers, e.g., voltage, power factor and current regulators. In 1946 and 1947 he was Consulting Engineer, being engaged in further development of magnetic amplifiers and the development of a solid state regulator for lighting machines in railroad cars. During his employment with Brown Boveri he was granted nine patents.

From 1947 to 1950 he was a Special Employee of the Ordnance Research and Development Division, Suboffice (Rocket), Department of the Army, Fort Bliss, Texas. He designed special apparatus and developed single and multistage magnetic amplifiers for missile applications.

Dr. Manteuffel was Deputy Chief, from 1950 to 1953, of the Research Laboratory, Guidance and Control Branch, Ordnance Guided Missile Center, Redstone Arsenal, Huntsville, Alabama, where he developed magnetic amplifiers, magnetic frequency doublers, magnetic voltage stabilizers, a magnetic mixing computer, and a frequency and voltage regulator of extremely high accuracy.

Since 1953, Dr. Manteuffel has been at the General Electric Advanced Electronics Center at Cornell University, where he is Consulting Engineer-Electrical Engineering in the Advanced Engineering Physics Subsection. He has technical leadership in investigations of magnetic circuits, including amplifiers, power supplies, modulators, and control systems. He has been granted four U.S. patents.

F. C. Schwarz

Mr. Schwarz attended technical universities in Germany and the Netherlands. In 1956, he received his MSEE from Columbia University. From 1956 to 1959 he did postgraduate work in Nonlinear Networks at Columbia University.

Since 1959, he has been working toward his doctorate in Electrical Engineering and Applied Mathematics at Cornell University.

Mr. Schwarz worked as independent consultant for servomechanism and automation from 1957 to 1959. He developed techniques in the field of automation of metal manufacturing processes.

He has been Project Engineer at General Electric's Advanced Electronics Center for the light weight, fast switching type power supply for the B-70 Radar Modulator. The project was preceded by invention and reduction to practice of pertinent techniques. He is responsible for development work on the ferro-resonant circuit, involving development and reduction to practice of new techniques for temperature and frequency stabilization of magnetic amplifiers. He has undertaken basic research of iron core devices leading to a substantial reduction in weight and size. He is also responsible for evaluation work in cryogenic electric engineering.

Mr. Schwarz is currently Project Engineer on the Switch Modulation Power Supply, for which he invented and reduced to practice the RC-inverter and the FM-SS inverter.

DISTRIBUTION LIST
SECOND QUARTERLY REPORT
CONTRACT NO. DA 36-039-SC-87353

Commanding Officer
U.S.A. Signal Research and Development Laboratory
Fort Monmouth, New Jersey
ATTN: Logistics Division (MARKED FOR PROJECT ENGINEER) 6
ATTN: SIGRA/SL-P 1
ATTN: SIGRA/SL-LNR 1
ATTN: SIGRA/SL-LNE 1
ATTN: Dir of Research/Engineering 1
ATTN: Technical Document Center 1
ATTN: Technical Information Div (UNCLASSIFIED REPORTS ONLY FOR RETRANSMITTAL TO ACCREDITED BRITISH AND CANADIAN GOVERNMENT REPRESENTATIVES) 3

OASD (R&D), Rm 3E1065
ATTN: Technical Library
The Pentagon
Washington 25, D.C. 1

Chief of Research and Development
OCS, Department of the Army
Washington 25, D.C. 1

Chief Signal Officer
ATTN: SIGRD
Department of the Army
Washington 25, D.C. 1

Chief Signal Officer
ATTN: SIGRD-4a
Department of the Army
Washington 25, D.C. 1

Director
U.S. Naval Research Laboratory
ATTN: Code 2027
Washington 25, D.C. 1

Commanding Officer & Director
U.S. Naval Electronics Laboratory
San Diego 52, California 1

Commander
Air Force Command and Control Development Division
ATTN: CRZC
L.G. Hanscom Field
Bedford, Massachusetts 1

Commander
Rome Air Development Center
ATTN: RAALD
Griffiss Air Force Base, New York 1

Commander General
U.S.A. Electronic Proving Ground
ATTN: Technical Library
Fort Huachuca, Arizona 1

Commanding Officer
Diamond Ordnance Fuze Laboratories
ATTN: Library, Room 211, Bldg. 92
Washington 25, D.C. 1

Commanding Officer
U.S.A. Signal Equipment Support Agency
ATTN: SIGMS-ADJ
Fort Monmouth, N.J. 1

U.S. Continental Army Command Liaison Office
U.S.A. Signal Research and Development Laboratory
Fort Monmouth, New Jersey
(QUARTERLY AND FINAL REPORTS FOR CONTRACTS COVERING EQUIPMENT AND SYSTEMS, FINAL REPORTS ONLY FOR OTHER CONTRACTS) 3

DISTRIBUTION LIST (cont'd)

Deputy President
U.S. Army Security Agency Board
Arlington Hall Station
Arlington 12, Virginia 1

Commander
Armed Services Technical Information Agency
ATTN: TIPCR
Arlington Hall Station
Arlington 12, Virginia 10

Chief
U.S. Army Security Agency
Arlington Hall Station
Arlington 12, Virginia 2

Commander
Aeronautical Systems Division
ATTN: ASAPRL
Wright-Patterson Air Force Base
Ohio 1

AFSC Liaison Office
Naval Air Research and Development Activities Command
Johnsville, Pennsylvania 1

Commander
Air Force Cambridge Research Laboratories
ATTN: CRO
L.G. Hanscom Field
Bedford, Massachusetts 1

Commander
Air Force Command and Control Development Division
ATTN: CCRR 1
ATTN: CCSD 1
L.G. Hanscom Field
Bedford, Massachusetts

Liaison Officer, LAA
U.S.A. Signal Research and Development Laboratory
75 South Grand Ave., Bldg. 13
Pasadena, California 1

Power Information Center
Moors School Building
200 South Thirty-Third Street
Philadelphia 4, Pennsylvania 1

Army Research Office
Office, Chief Research & Development
Department of the Army
Room 3D442, The Pentagon
Washington 25, D.C.
ATTN: Dr. Sidney J. Magram 1

Director Advanced Concepts Division
Bureau of Ships (Code 350)
Washington 25, D.C.
ATTN: LCDR, Frank W. Anders 1

Office of Naval Research (Code 429)
Department of the Navy
Washington 25, D.C.
ATTN: Mr. James R. Patton, Jr. 1

Headquarters
USAF (AFRDR-AS)
Washington 25, D.C.
ATTN: Maj. William G. Alexander 1

Commander
Aeronautical Systems Division
Wright-Patterson Air Force Base
Ohio
ATTN: Mr. George W. Sherman 1

Assistant Director, Material Sciences
Advanced Research Projects Agency
The Pentagon, Room 3E153
Washington 25, D.C.
ATTN: Mr. Charles F. Yost 1

DISTRIBUTION LIST (cont'd)

Advanced Research Projects Agency
The Pentagon, Room 3E157
Washington 25, D.C.
ATTN: Dr. John H. Huth 1

U.S. Atomic Energy Commission
Division of Reactor Development
Washington 25, D.C.
ATTN: Mr. G. Montgomery Anderson 1

U.S. Atomic Energy Commission
Division of Reactor Development
Auxiliary Power Branch (SNAP)
Washington 25, D.C.
ATTN: Lt. Col. George H. Ogburn, Jr. 1

National Aeronautics & Space Administration
1520 H. Street, N.W.
Washington 25, D.C.
ATTN: Mr. David Novik (RPP) 1

National Aeronautics & Space Administration
1520 H. Street N.W.
Washington 25, D.C.
ATTN: Mr. Walter C. Scott 1

Equipment & Supplies Division
Office of Ordnance
Office, DODR&L
The Pentagon
Washington 25, D.C.
ATTN: Mr. G.B. Wareham 1

Walter Kidde, Inc.
Electronics Department
9 Brighton Road
Allwood, Clifton, New Jersey
ATTN: Mr. E. Olster 1

Engineered Magnetics
Division of Gulton Industries, Inc.
13030 Cerise Avenue
Hawthorne, California
ATTN: Mr. J. Alexakis 1

United Aircraft Corporation
Hamilton Standard Division
Broad Brook, Connecticut
ATTN: Mr. Raymond Russ 1

Consolidated Avionics Corp.
800 Shames Drive
Westbury, L.I., New York
ATTN: Mr. W. Perzley 1

Varo Manufacturing Co., Inc.
2201 Walnut St.
Garland, Texas
ATTN: Mr. W. Bonds 1

Sorensen & Co., Inc.
South Norwalk, Connecticut
ATTN: Mr. C. Mikosky 1

Westinghouse Electric Corp.
43 West Front Street
Red Bank, N.J. 1

Electrosolids Corp.
12740 San Fernando Road North
Sylmar, California 1

Technical Operations, Inc.
Burlington, Massachusetts
ATTN: Mr. Robert Smyth 1

Sun Electric Corp.
Aeronautical Division
Harlem & Avondale
Chicago 31, Illinois 1

Ovitron Corp.
37-05 48th Ave.
Long Island City 1, New York
ATTN: Mr. L. Ward 1

Bendix - Red Bank
Div. of Bendix Aviation Corp.
Eatontown, New Jersey
ATTN: Mr. M. Roberti 1

DISTRIBUTION LIST (cont'd)

Alexander Kusko, Inc. 141 Main Street Cambridge 42, Massachusetts ATTN: Mr. A. Kusko	1
Temco Electronics & Missiles Co. P.O. Box 6191 Dallas 22, Texas	1
Minneapolis-Honeywell Regulator Co. Military Products Group P.O. Box 161 Union, New Jersey	1

AD

Advanced Electronics Center, General Electric Company
Ithaca, New York
SWITCH MODULATION TECHNIQUES by Francisc C. Schwarz
3rd Quarterly Report: Features of the Frequency-Modulated Self-Stabilizing Power Modulator. 1 Feb. 1962 to 30 Apr. 1962 30 pp, 6 refs.
Signal Corps Contract DA-36-039-SC-87353
Dept. of the Army Task No. 3A99-09-002-05 Unclassified Report

The saturable reactors were replaced by an electronic integrator, simulating operation of the saturable reactors with an improvement in accuracy of two orders of magnitude. The entire control system was redesigned following the discovery of insufficient accuracy in functional aspects, which were not apparent with operation of saturable reactors. A breadboard of the 260-watt unit except feedback and reference sources was established and brought to operation. An automatic adjustment of the system to the two line voltages in question, 115 and 230 v ac respectively, was devised. Electrical design of both units, items (2) and (3) of the contract, was completed and schematics established. Electrical and mechanical designs were completed, component specifications established, and their procurement carried out. Physical construction of 260- and 600-watt units was completed. Preliminary test data on the 260-watt unit indicate that achievement of the objectives of the program (especially weight reduction and functional reliability) can be expected.

UNCLASSIFIED
1. AC to DC Conversion Switch Modulation Technique
2. Modulator-Frequency Modulated Self-Stabilizing
I. Power Supply
II. Schwarz, Francisc C.
III. USA Electronics Research and Development Laboratory
IV. Signal Corps Contract DA-36-039-SC-87353

UNCLASSIFIED

AD

Advanced Electronics Center, General Electric Company
Ithaca, New York
SWITCH MODULATION TECHNIQUES by Francisc C. Schwarz
3rd Quarterly Report: Features of the Frequency-Modulated Self-Stabilizing Power Modulator. 1 Feb. 1962 to 30 Apr. 1962 30 pp, 6 refs.
Signal Corps Contract DA-36-039-SC-87353
Dept. of the Army Task No. 3A99-09-002-05 Unclassified Report

The saturable reactors were replaced by an electronic integrator, simulating operation of the saturable reactors with an improvement in accuracy of two orders of magnitude. The entire control system was redesigned following the discovery of insufficient accuracy in functional aspects, which were not apparent with operation of saturable reactors. A breadboard of the 260-watt unit except feedback and reference sources was established and brought to operation. An automatic adjustment of the system to the two line voltages in question, 115 and 230 v ac respectively, was devised. Electrical design of both units, items (2) and (3) of the contract, was completed and schematics established. Electrical and mechanical designs were completed, component specifications established, and their procurement carried out. Physical construction of 260- and 600-watt units was completed. Preliminary test data on the 260-watt unit indicate that achievement of the objectives of the program (especially weight reduction and functional reliability) can be expected.

UNCLASSIFIED
1. AC to DC Conversion Switch Modulation Technique
2. Modulator-Frequency Modulated Self-Stabilizing
I. Power Supply
II. Schwarz, Francisc C.
III. USA Electronics Research and Development Laboratory
IV. Signal Corps Contract DA-36-039-SC-87353

UNCLASSIFIED

AD

Advanced Electronics Center, General Electric Company
Ithaca, New York
SWITCH MODULATION TECHNIQUES by Francisc C. Schwarz
3rd Quarterly Report: Features of the Frequency-Modulated Self-Stabilizing Power Modulator. 1 Feb. 1962 to 30 Apr. 1962 30 pp, 6 refs.
Signal Corps Contract DA-36-039-SC-87353
Dept. of the Army Task No. 3A99-09-002-05 Unclassified Report

The saturable reactors were replaced by an electronic integrator, simulating operation of the saturable reactors with an improvement in accuracy of two orders of magnitude. The entire control system was redesigned following the discovery of insufficient accuracy in functional aspects, which were not apparent with operation of saturable reactors. A breadboard of the 260-watt unit except feedback and reference sources was established and brought to operation. An automatic adjustment of the system to the two line voltages in question, 115 and 230 v ac respectively, was devised. Electrical design of both units, items (2) and (3) of the contract, was completed and schematics established. Electrical and mechanical designs were completed, component specifications established, and their procurement carried out. Physical construction of 260- and 600-watt units was completed. Preliminary test data on the 260-watt unit indicate that achievement of the objectives of the program (especially weight reduction and functional reliability) can be expected.

UNCLASSIFIED
1. AC to DC Conversion Switch Modulation Technique
2. Modulator-Frequency Modulated Self-Stabilizing
I. Power Supply
II. Schwarz, Francisc C.
III. USA Electronics Research and Development Laboratory
IV. Signal Corps Contract DA-36-039-SC-87353

UNCLASSIFIED

AD

Advanced Electronics Center, General Electric Company
Ithaca, New York
SWITCH MODULATION TECHNIQUES by Francisc C. Schwarz
3rd Quarterly Report: Features of the Frequency-Modulated Self-Stabilizing Power Modulator. 1 Feb. 1962 to 30 Apr. 1962 30 pp, 6 refs.
Signal Corps Contract DA-36-039-SC-87353
Dept. of the Army Task No. 3A99-09-002-05 Unclassified Report

The saturable reactors were replaced by an electronic integrator, simulating operation of the saturable reactors with an improvement in accuracy of two orders of magnitude. The entire control system was redesigned following the discovery of insufficient accuracy in functional aspects, which were not apparent with operation of saturable reactors. A breadboard of the 260-watt unit except feedback and reference sources was established and brought to operation. An automatic adjustment of the system to the two line voltages in question, 115 and 230 v ac respectively, was devised. Electrical design of both units, items (2) and (3) of the contract, was completed and schematics established. Electrical and mechanical designs were completed, component specifications established, and their procurement carried out. Physical construction of 260- and 600-watt units was completed. Preliminary test data on the 260-watt unit indicate that achievement of the objectives of the program (especially weight reduction and functional reliability) can be expected.

UNCLASSIFIED
1. AC to DC Conversion Switch Modulation Technique
2. Modulator-Frequency Modulated Self-Stabilizing
I. Power Supply
II. Schwarz, Francisc C.
III. USA Electronics Research and Development Laboratory
IV. Signal Corps Contract DA-36-039-SC-87353

UNCLASSIFIED